POLARIZATION EFFECTS IN DRELL-YAN TYPE PROCESSES $h_1 + h_2 \to (W, Z, \gamma^*, J/\psi) + X$

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ABSTRACT

The measurement of the angular distribution of leptons from the decay of a W, Z, γ^*, or J/ψ produced at high transverse momentum in hadronic collisions provides a detailed test of the production and decay mechanism of the spin one state. In the absence of cuts on the final state leptons, the lepton angular distribution in the lepton pair rest frame is determined by the polarization of the spin one state. At leading order in perturbative QCD the general structure of the decay lepton distribution arising from a W, Z [$\gamma^*, J/\psi$] is controlled by six [four] invariant structure functions. In the presence of cuts, the lepton angular distributions are dominated by kinematic effects rather than polarization effects. We present Monte Carlo studies for Tevatron energies and discuss how polarization effects can be highlighted in the presence of cuts.

The physics of a gauge boson or a J/ψ produced at high transverse momentum at hadron colliders is a rich source of information on many aspects of the physics of the standard model [1, 2, 3, 4]. For gauge bosons or J/ψ's produced with transverse momentum p_T, the event plane spanned by the beam and the spin-one state momentum directions provides a convenient reference plane for studying the angular distributions of the decay leptons. In leading order QCD the angular distribution of the leptons from a gauge boson V [$V = W, Z, \gamma^*$] has the general form:

$$\frac{d\sigma}{dp_T^2\, dy\, d\cos\theta\, d\phi} = \frac{3}{16\pi}\frac{d\sigma_{U+L}^V}{dp_T^2\, dy}\left[(1+\cos^2\theta) + \frac{1}{2}A_0^V\ (1-3\cos^2\theta) + A_1^V\ \sin 2\theta\cos\phi + \frac{1}{2}A_2^V\ \sin^2\theta\cos 2\phi + A_3^V\ \sin\theta\cos\phi + A_4^V\ \cos\theta\right],$$

where θ and ϕ denote the polar and azimuthal angle of the decay leptons in the lepton pair rest frame. The coefficients A_i are functions of the transverse momentum p_T and the rapidity y of the gauge boson V. For $V = \gamma^*$, the parity violating coefficients A_3 and A_4 are zero. The unpolarized differential production cross section is denoted by

[1]Talk presented by E. Mirkes at the DPF94 Meeting, Albuquerque, New Mexico, USA; August 2-6, 1994.

σ_{U+L} whereas the coefficients A_i characterize the polarization of the spin-one state, *e.g.*, the cross section contribution of the longitudinal polarization is denoted by A_0, the transverse-longitudinal interference contribution by A_1, the transverse interference cross section by A_2, *etc* [all with respect to the z-axis of the chosen lepton pair rest frame]. [2, 3] With the replacements $V \to J/\psi$ and $A_{3,4} \to 0$, the general form of Eq. (1) is also valid for the decay lepton distribution arising from the decay of a J/ψ produced at high transverse momentum in hadronic collisions [4].

The coefficients A_i are dependent on the choice of the z-axis in the lepton pair rest frame. We will present results here for the Collins-Soper [1] (CS) frame. In this frame the z-axis bisects the angle between the proton and negative anti-proton direction. For W decay, this frame has the unique advantage that the polar and azimuthal angles θ and ϕ can be reconstructed modulo a sign ambiguity in $\cos\theta$ without information on the longitudinal momentum of the neutrino [2, 3]. The complete next-to-leading-order (NLO) corrections to the parity conserving coefficients were calculated in Ref. 2 and were found to be fairly small [less than 10%]. It is thus sufficient to use LO matrix elements in the Monte Carlo study presented in this paper. Figure 1 shows the normalized ϕ and $\cos\theta$ distributions for the leptons from the decay of a Z boson for four bins in the transverse momentum of the Z boson. No acceptance cuts have been applied to the leptons. For a more realistic analyses, one has to impose acceptance cuts and energy resolution smearing to the leptons. When imposing the cuts $p_T(l) > 25$ GeV and $|y(l)| < 1$ to the leptons, the shapes of the lepton angular distributions are dominated by kinematic effects and the residual dynamical effects from the gauge boson polarization are small. Polarization effects can be maximized by minimizing the cuts, however, this strategy is severly limited since cuts are needed to reject background events. Therefore, to regain sensitivity to the polarization effects in the presence of large kinematic cuts, we propose to divide the experimental distributions by the Monte Carlo distributions obtained using isotropic gauge boson decay. The large effects of the cuts [and smearing in the W case [3]] are expected to almost cancel in this ratio. Figure 2 shows the ratio of the ϕ and $\cos\theta$ distributions for the Z with full polarization to the corresponding distributions obtained with isotropic Z decay for the same bins as in Fig. 1. Energy resolution smearing and the cuts $p_T(l) > 25$ GeV and $|y(l)| < 1$ are included. The ratios contain most of the polarization dependence seen in Fig. 1. A detailed Monte Carlo analyses of the decay angular distributions of W's and Z's produced at Tevatron energies is presented in Ref. 3. Analytical and numerical results [calculated in the nonrelativistic bound state model] for the decay lepton distribution of high p_T J/ψ's can be found in Ref. 4. All distributions are fairly insensitive to the scales in the strong coupling constant and the choice of the parton distribution functions.

References

[1] J. C. Collins and D. E. Soper, Phys. Rev. **D16**, 2219 (1977).

[2] E. Mirkes, Nucl. Phys. **B387**, 3 (1992).

[3] E. Mirkes and J. Ohnemus, preprint, MAD/PH/834, UCD-94-23, June, 1994.

[4] C. S. Kim and E. Mirkes, preprint, MAD/PH/820, YUMS-94-11, July, 1994.

FIGURE CAPTIONS

Fig. 1 a) Normalized ϕ and b) normalized $\cos\theta$ distributions of the negatively charged lepton from Z boson decay in the CS frame. Results are shown for four bins in $p_T(Z)$:
10 GeV $< p_T(Z) <$ 20 GeV (solid),
20 GeV $< p_T(Z) <$ 30 GeV (dashed),
30 GeV $< p_T(Z) <$ 70 GeV (dots),
70 GeV $< p_T(Z)$ (dot-dashed).
No cuts or smearing have been applied.

Fig. 2 Ratios of distributions obtained with full polarization effects to those obtained with isotropic decay of the Z boson. Parts a) and b) are the ratios for the ϕ and $\cos\theta$ distributions, respectively. Energy resolution smearing and the cuts $p_T(l) > 25$ GeV and $|y(l)| < 1$ are included.

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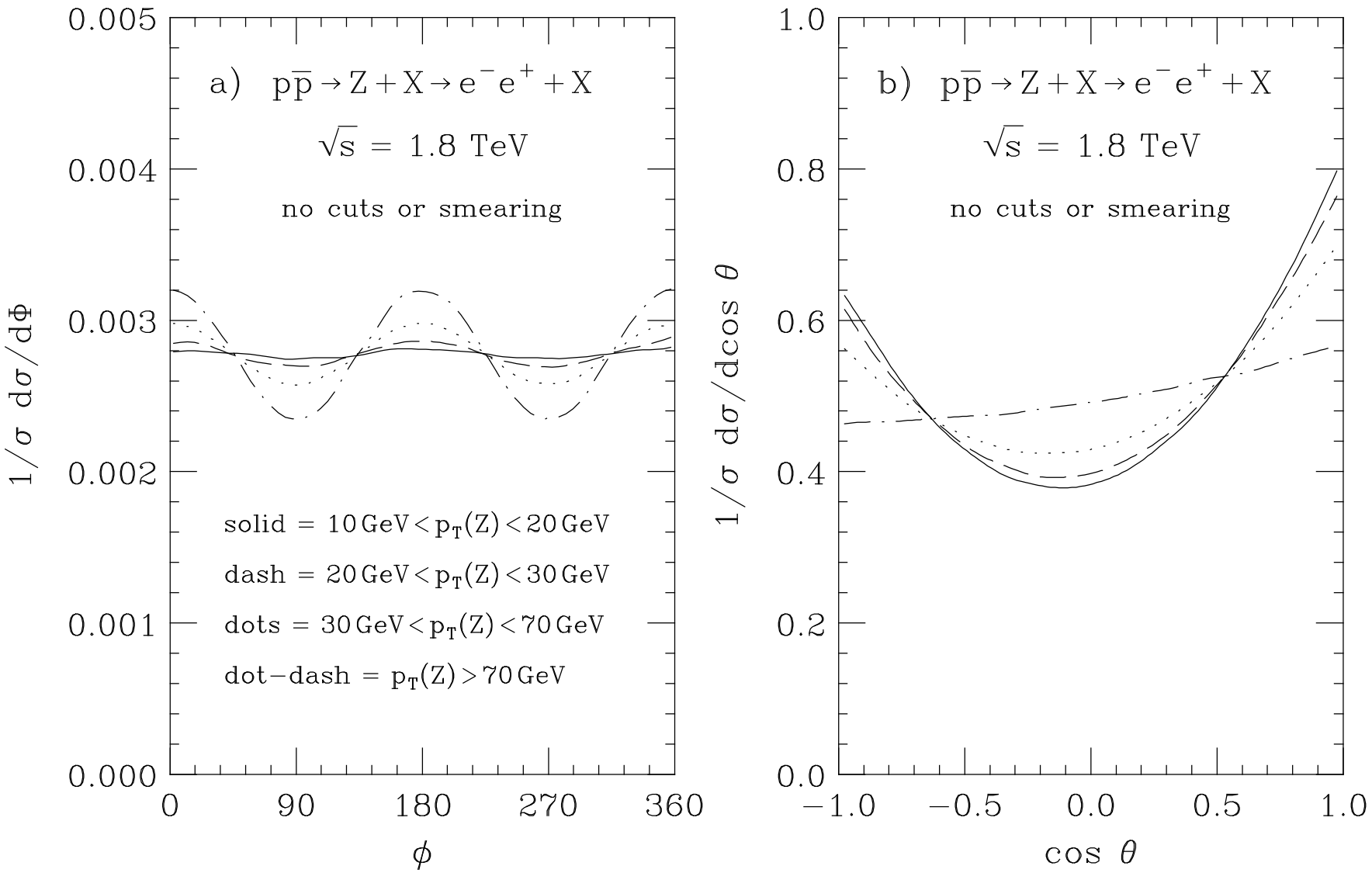
a) $p\bar{p} \to Z + X \to e^- e^+ + X$
$\sqrt{s}$ = 1.8 TeV
no cuts or smearing
solid = 10 GeV < $p_T(Z)$ < 20 GeV
dash = 20 GeV < $p_T(Z)$ < 30 GeV
dots = 30 GeV < $p_T(Z)$ < 70 GeV
dot−dash = $p_T(Z)$ > 70 GeV
$1/\sigma\ d\sigma/d\Phi$
ϕ
0.000
0.001
0.002
0.003
0.004
0.005
0
90
180
270
360
b) $p\bar{p} \to Z + X \to e^- e^+ + X$
$\sqrt{s}$ = 1.8 TeV
no cuts or smearing
$1/\sigma\ d\sigma/d\cos\theta$
$\cos\theta$
0.0
0.2
0.4
0.6
0.8
1.0
−1.0
−0.5
0.0
0.5
1.0

Figure 9

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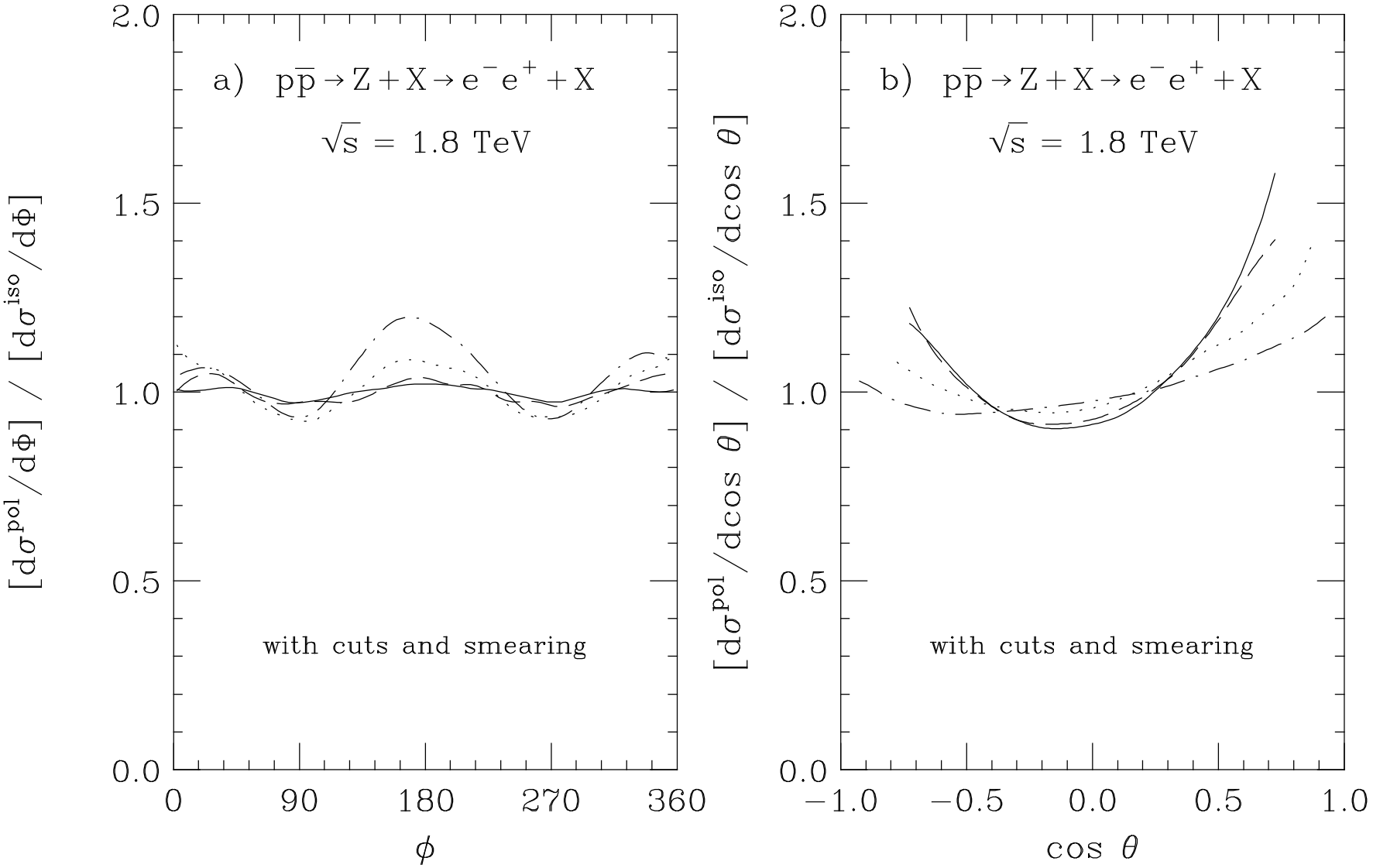
a) $p\bar{p} \to Z + X \to e^- e^+ + X$
$\sqrt{s}$ = 1.8 TeV
with cuts and smearing
$[d\sigma^{pol}/d\Phi] / [d\sigma^{iso}/d\Phi]$
ϕ
0.0
0.5
1.0
1.5
2.0
0
90
180
270
360
b) $p\bar{p} \to Z + X \to e^- e^+ + X$
$\sqrt{s}$ = 1.8 TeV
with cuts and smearing
$[d\sigma^{pol}/d\cos\theta] / [d\sigma^{iso}/d\cos\theta]$
$\cos\theta$
−1.0
−0.5
0.0
0.5
1.0

Figure 11